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The Real Footprint of Electric Vehicles, and What That Could Mean For Our Future

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Introduction and Overview of Methodology:

The Electric Vehicles industry has been growing rapidly over the past few years. Increasing knowledge of global warming, and visible effects have created a sense of urgency for the public to make conscious decisions to reverse or slow the impact. Based on data from 2013, the transportation sector takes up around 28% of the total United States energy consumption, and thus changes in this sector are as helpful to our environment as any.[1] The increasing population, and the growing number of vehicles per family in the United States have shaped the increasing demand for this "environmentally conscious" industry.

The research hopes to answer the question of whether or not CO2 emissions will in fact be lowered as electric cars start to make up the majority of vehicles in use. The hypothesis is that C02 emissions released from the transportation sector will be lower when comparing electric cars versus conventional cars, but will vary depending on the type of electricity used. The paper will also demonstrate that the emissions count from electric cars could be improved if shift our generation of electricity to the technologies which release the lowest levels of C02. Supporters of electric vehicle look at the consumption of gas and how that is decreased by the use of hybrid or plug-in vehicles, however many do not take into account the use of different technologies for the generation of electricity and the resulting emissions from such generation. If we have to start increasing the production of electricity to provide for the increase in electric vehicles, the emissions count from production of electricity will also rise, and may have a more negative effect than what is currently being assessed and estimated.

This paper examines the impact of electric vehicles on emissions through the following methodology. It is first necessary to determine the mix of electricity generation technologies in each state, and to assess the amount of greenhouse gas emissions associated with each unit of electricity generated by each technology. That data is then combined with the amount of electricity necessary to drive an electric fleet in each state to determine the CO2 emissions associated with driving electric vehicles. This data is then compared with the amount of CO2 emissions associated with driving an equivalent number of conventional vehicles.

Literature:

Previous research on the topic of environmental benefits from the use of electric cars started in the early 2000's. In 2009, Muller and Mendelsohn published, "Efficient Pollution Regulation: Getting the Prices Right" arguing that regulators could use new data on source-specific damages to switch the market-based

[1] Davis, Stacy Cagle, Susan W. Diegel, Robert Gary Boundy, and Sheila A. Moore. "2014 Vehicle Technologies Market Report." (2015): n. pag. *Oak Ridge National Laboratory*. Office of Energy Efficiency and Renewable Energy: U.S. Department of Energy. Web. 20 Nov. 2015. <http://cta.ornl.gov/vtmarketreport/pdf/2014_vtmarketreport_full_doc.pdf>.

pollution policies from cost effectiveness to efficiency. They found that air pollution damages depend on the location of emissions. The damages from driving motor vehicles in one place can differ significantly from the damages associated with driving the same motor vehicle in another place. [2] Their study concluded that conventional vehicles emit pollutants at or near the ground while electric power plants that produce energy for electric cars have the pollution discharge occur hundreds of feet above ground level, being yet another distinction between the damages of the two types of vehicles.[3] This is directly related to my research because the factor of pollutants from the production of electricity was examined in Muller and Mendelsohn's work, where in many cases it is left out of the damages caused from the use of electric cars. My examination of the impact of electric vehicles on CO2 emissions based on the type of electricity used could have a more precise calculation by accounting for the location of emissions release.

Earlier this year Erin Mansur and Stephen Holland published a paper using much of Muller and Mendelsohn's findings and looked at the benefits of electric vehicles relative to conventional gasoline vehicles, and analyzed the welfare associated with policies such as subsidies on purchasing electric vehicles and taxes on both electric and gasoline miles driven. Their work looks more at the purchase of an electric vehicle and the benefits that come from that, rather than focusing on the environmental benefits of the car itself. When they do look at the environmental differences, they focus specifically on five different air pollutants rather than looking at total CO2 emissions from the production of electricity versus the CO2 production from the combustion of gasoline.[4]

Data:

This paper will specifically be using data from states in New England to calculate the estimated CO2 levels produced by electric vehicles when accounting for each type of electricity used to power the transportation sector. In 2010 the total number of state private and commercial (including taxis) automobile registrations in New England was 6,985,707. Broken-down to the state level, Massachusetts led with 3,122,244, followed by Connecticut with 1,973,586. New Hampshire had the third most with 614,113, followed by Maine, Rhode Island, and Vermont with 512,379; 473,647; and 289,738 respectively. [5] When using the simple equation

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[2] Muller, Nicholas, and Robert Mendelsohn. "Document Request." *AEA Web*. American Economic Review, 2009. Web. 29 Nov. 2015. <http://pubs.aeaweb.org/doi/pdfplus/10.1257/aer.99.5.1714>.
[3] Ibid.
[4] Holland, Stephen, Erin Mansur, Nicholas Muller, and Andrew Yates. "Environmental Benefits from Driving Electric Vehicles?" *National Bureau of Economic Research* (2015)
[5] "Highway Statistics Series." *Office of Highway Policy Information*. Federal Highway Administration, 7 Nov. 2014. Web. 25 Nov. 2015. <https://www.fhwa.dot.gov/policyinformation/statistics/2010/mv1.cfm>.

below, we can estimate the fraction of electric cars out of the total number of cars in each state:

*(# of Electric Vehicle's Registered per State) / (Total number of Registered Vehicles per state) *100 = Percent of Registered Vehicles that are Electric in each State*

Table 1:

	Private Automobile Registration 2010	Electric Vehicle Registration 2014	% Registered Automobiles That are Electric
ME	512,379	15,303	2.99%
NH	614,113	17,633	2.87%
VT	289,738	10,028	3.46%
MA	3,122,244	87,952	2.82%
RI	473,647	9,837	2.08%
CT	1,973,586	39,001	1.98%
Total:	6,985,707	179,754	2.57%

*Electric Vehicle Registration data is from the US Department of Energy; June 1, 2015 Hybrid Electric Vehicle Penetration by State, 2014. [6]

Looking at electric vehicle registration data from 2014 collected by the US Department of Energy, we can see in Table 1 that in these New England states, the percentage of registered vehicles that are electric is still very small. It is important to note that the third column showing the calculated percent of registered automobiles that are electric vehicles is clearly showing estimated percentages because the first set of data is from 2010 while the second is from 2014, however because the total automobile registration numbers have not increased by a huge sum between those three years, we can assume that the numbers are not far off the true value. If anything, the total number of registered vehicles in these states would be greater relative to the electric vehicle registration number, meaning the percent is even smaller and all noticeable effects (both good and bad) from electric vehicle use are more difficult to quantify.

One of the most important numbers estimated in this paper is the conversion between kilowatt-hours and miles per gasoline consumption. The conclusions drawn from this research hinge on this estimated translation because that is what allows the comparison between the two types of motor vehicles. The EPA uses an established energy standard of 115,000 BTU's per gallon of gasoline. To create the same amount of energy, one would need around 33.5 kilowatt-hours of electricity. Specific to cars, the 2014 electric vehicle model Ford Focus could travel 100 miles

[6] "2015 Hybrid Electric Vehicle Penetration by State, 2014." *Fact #875: June 1, 2015 Hybrid Electric Vehicle Penetration by State, 2014*. US Department of Energy, May 2015. Web. 26 Nov. 2015. <http://energy.gov/eere/vehicles/fact-875-june-1-2015-hybrid-electric-vehicle-penetration-state-2014>.

on about 33.5 kilowatt-hours of electricity. 33.5 kilowatt-hours is slightly lower than the real calculated value because electric vehicles can capture and store some of the energy that would otherwise be lost in braking. This means that comparing long highway drives, the two vehicles are more similar in energy usage because the additional energy recaptured from braking with the electric vehicle is very low during highway driving. [7] All electric vehicles consume somewhat different amounts of electricity, but the mean energy consumption of the top electric vehicle models is about 33.5 kilowatt-hours. This is the number that will be used throughout the paper when comparing electric and conventional vehicles and the CO2 emissions released from miles driven.

The calculations that follow are presented with data from the EIA and Highway Policy Information cites. The first calculation is getting the percent of private and commercial vehicles in the entire motor vehicles sector, so that the effects from private and commercial trucks and private and commercial buses can be eliminated. This percent that accounts for vehicles of interest is then multiplied by total energy consumption in the transportation sector to get the total energy consumption per state by the vehicles of interest, shown in Table 3. Table 2 is just the consolidated information from the EIA website with state level energy consumption.

National electricity data in the transportation sector is given to all types of road transportation. This means the estimated electricity consumption in the transportation sector measures the aggregate consumption of these motor vehicles. To have more accurate estimations of electricity consumed by private conventional and electric vehicles, the percent of ground transportation that is private and commercial motor vehicles was calculated in Table 2 using the equation below for each state:

*(Total private and commercial automobiles in 2010) / (Total motor-vehicles registered in 2010) *100 = Percent of motor-vehicles that are automobiles of interest*

[7] Seredynski, Paul. "Understanding Electric Car MPG on Edmunds.com." *Edmunds.com*. Edmunds, 2014. Web. 29 Nov. 2015. <http://www.edmunds.com/fuel-economy/decoding-electric-car-mpg.html>.

Table 2:

	All Motor-Vehicle Registrations 2010	% motor-vehicles that are automobiles 2010
ME	1053842	48.62%
NH	1202974	51.05%
VT	566650	51.13%
MA	5333915	58.54%
RI	782438	60.53%
CT	3082011	64.04%
Total:	12,021,830	58.11%

*Data collected from Office of Highway Policy Information.[8]

These numbers were then used to calculate the amount of energy consumed by motor vehicles of interest (labeled cars in the lower half of Table 3) using a similar calculation:

*Percent of motor-vehicles that are automobiles (2010) * Total energy consumption in the transportation sector (2013) = Estimated total energy consumption (btu) by cars of interest*

The first half of the table shown is the direct data from the EIA, giving state specific totals of energy consumption in the transportation sector in trillion btu's. The second half illustrates the energy consumption when only looking at the electric vehicle automobiles of interest.

Table 3:

2013	Total enrgy consump. transportation sector (tril btu)
ME	128
NH	99.4
VT	49.2
MA	456.2
RI	58.3
CT	228
Total:	1019.1
Given % electric cars from motor vehicles 2.57%: energy consumption by electric vehicle	
ME	3.82
NH	2.85
VT	1.70
MA	12.85
RI	1.21
CT	4.51
Total:	26.22

*Data from EIA.[9]

[8] "Highway Statistics Series." *Office of Highway Policy Information*. Federal Highway Administration, 7 Nov. 2014. Web. 25 Nov. 2015. <https://www.fhwa.dot.gov/policyinformation/statistics/2010/mv1.cfm>.

[9] "Total Energy Consumption, Price, and Expenditure Estimates, 2013." *US State Profiles and Energy Estimates*. US Energy Information Administration, 2014. Web. 15 Nov. 2015.

In Table 4 there is the breakdown of the energy used in the transportation sector in 2014 in the entire US, we can see that petroleum is clearly the largest consumed. Petroleum/gasoline combustion creates 71.3 kilograms of CO2 per million Btu.[10] This makes sense because conventional vehicles are still the main source of transportation.

Table 4:

Transportation Sector Energy Consumption 2014: (trillion btu)			% of Type Used Given Primary Total:
Coal		0	0.00%
Natural Gas		899	3.33%
Petroleum		24839	91.90%
Total fossil fuels		25738	95.23%
Biomass		1289	4.77%
Total Primary		27027	100.00%

*Data from EIA

When taking out the conventional vehicles, one can estimate electric vehicle emissions based on the generation mix at the state level. First is compiling the amount of emissions per kilowatt-hour for each source and multiply that by the percentages to come up with a blended number for emissions per kilowatt-hour. Then a calculation is made by multiplying that with the number if kilowatt-hours consumed by electric cars to get the amount of emissions Maine drivers emit in an electrical vehicle per 100 miles. Comparing this with a conventional vehicle will show the difference in types of fuel used and the CO2 emissions produced.

<http://www.eia.gov/state/seds/data.cfm?incfile=/state/seds/sep_fuel/html/fuel_te.html&sid=US&sid=ME>.

[10] "Carbon Dioxide Emissions Coefficients." *Environment - U.S. Energy Information Administration*. US Energy Information Administration, Feb. 2013. Web. 24 Nov. 2015. <https://www.eia.gov/environment/emissions/co2_vol_mass.cfm>.

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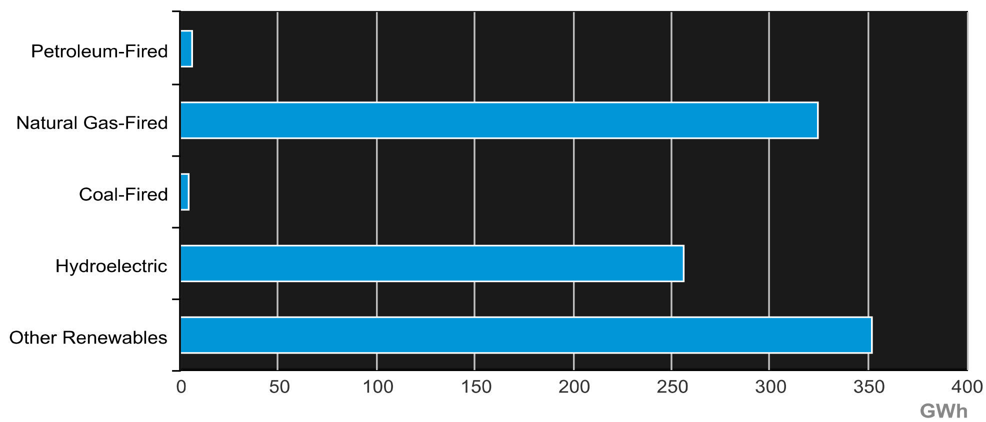
Maine Net Electricity Generation by Source, Aug. 2015



Source: Energy Information Administration, Electric Power Monthly

*Note one GWh is 1,000,000 kilowatt-hours

Compared with gasoline, natural gas production is more environmentally friendly when comparing CO2 emissions, however when you compare natural gas to hydropower, we see that there is room to improve in terms of decreasing emissions. Gasoline produces an average of 821 grams of CO2 per kilowatt-hour. Hydropower releases 4 grams of CO2 per kilowatt-hour while natural gas produces an average of 465 grams per kilowatt-hour, both being much better than coal, which produces an average of 909 grams of CO2 emission per kilowatt-hour.[11] The graph on the final page gives a visual of emissions levels given the production type.

Maine's electricity generation mix is predominantly made of renewable and natural gas-fired energy. [12] However, the specific blend using the data from the EIA to produce the graph above is as follows:

Category	Maine Net Electricity Generation GWh (Sept '15)	% of Total
Petroleum-Fired	13	2%
Natural Gas-Fired	268	31%
Coal-Fired	5	1%
Hydroelectric	230	27%
Other Renewables	344	40%
Total:	860	100%

[11] http://blueskymodel.org/kilowatt-hour
[12] "Maine." *US Energy Information Administration*. US Department of Energy, 2015. Web. <http://www.eia.gov/state/?sid=ME#tabs-4>.

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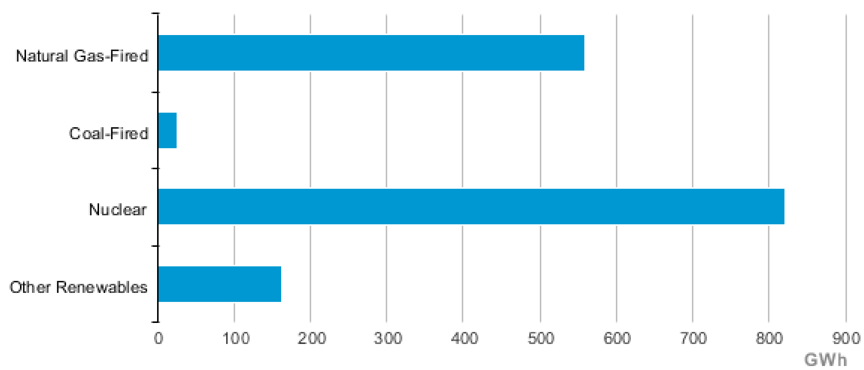
The Maine Net Electricity Generation GWh was downloaded data, and the % of Total was calculated by dividing the specific category from the total. Accounting for the conversion from GWh to KWh (multiplying all numbers by 1,000,000), the estimated blend is thus emitting 13*821 grams of CO2 (petroleum) + 230*4 grams of CO2 (hydroelectric) + 5*909 grams of CO2 (coal) + 268*465 grams of CO2 (natural gas) + 344* 0 grams of CO2 (renewables) = 1.4e11 grams of CO2 per kilowatt-hour in the month of August 2015. Converting to pounds, that is 309667600 lbs of CO2 per kilowatt-hour. Using the estimated 33.5 kilowatt hours to travel 100 miles in an electric vehicle, we can estimate the CO2 emissions from driving 100 miles in an electric vehicle during the month of August 2015 in Maine was around 1.03e10 lbs.

To compare to a conventional car, we need a few basic calculations first 1 kWh contains 3,412 btu, and 1 gallon of gasoline contains 115,000 btu. To travel 100 miles, conventional cars need an estimated 25 mpg we can calculate 115,000 / 3,412 = 33.7 kWh*(100/25mpg) = 134.8 kWh per 100 miles. Now, using 100% petroleum-fired electricity, the calculation would be (860*1000000)(821 grams of C02 from petroleum production))= 1.04e11 grams*(.0022) = 1553332000 lbs of CO2 per kilowatt-hour * 134.4 kilowatt-hours per 100 miles = 2.09e11 lbs CO2 per 100 miles driven.

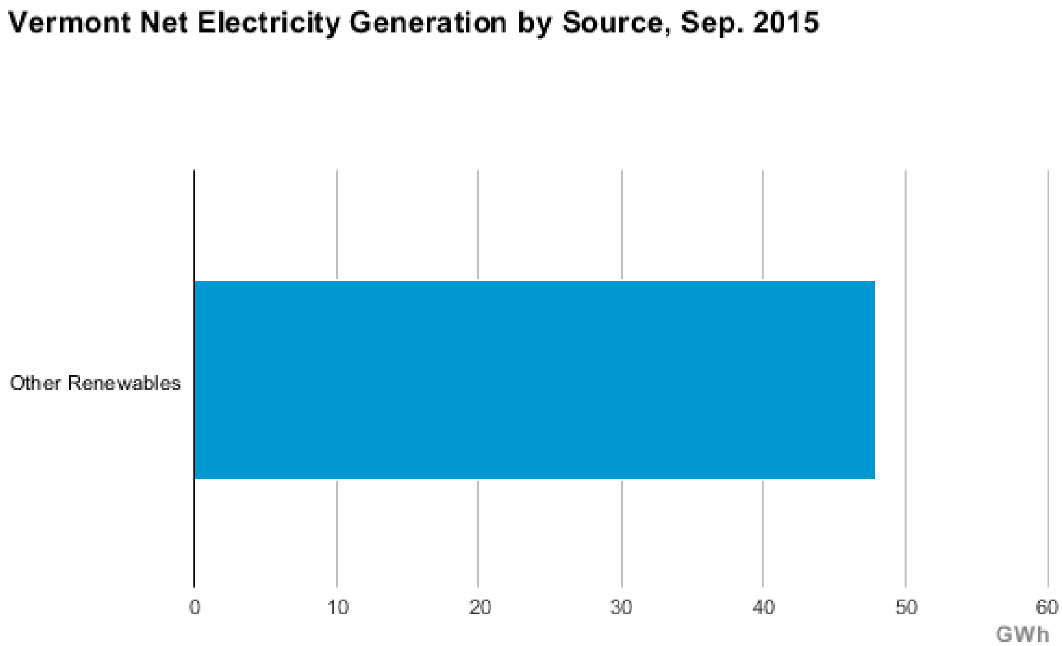
Clearly there is a remarkable difference. However when comparing to the possibility of only renewable energy which would have zero emissions all together, there is a lot of room for improving our electricity production used to power these vehicles. The Vermont data is very unclear but if other renewable sources really did emit zero CO2 emissions, they should be the state others mimic.

New Hampshire Net Electricity Generation by Source, Sep. 2015



*EIA data and graph

New Hampshire is somewhat different in that its main source of electricity in its generation mix is from nuclear power. Nuclear power produces an average of 6 grams of CO_2 per kilowatt-hour, clearly being the most environmentally friendly of the three types examined so far.



*EIA data and graph

Vermont was impossible to examine with the data referencing other renewables as their generation mix, not commenting on the type. The smaller scale productions such as hydropower, solar power, or many other smaller types that are lumped into the other renewables category.

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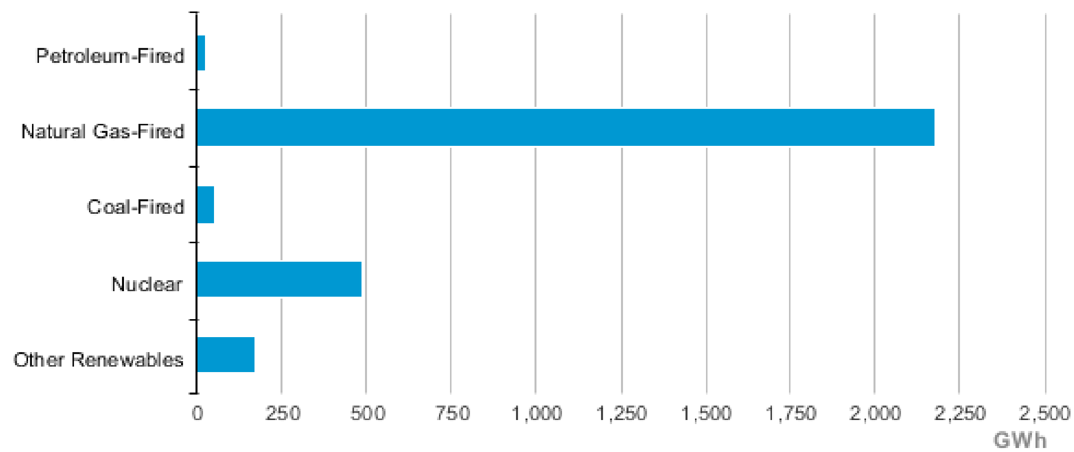
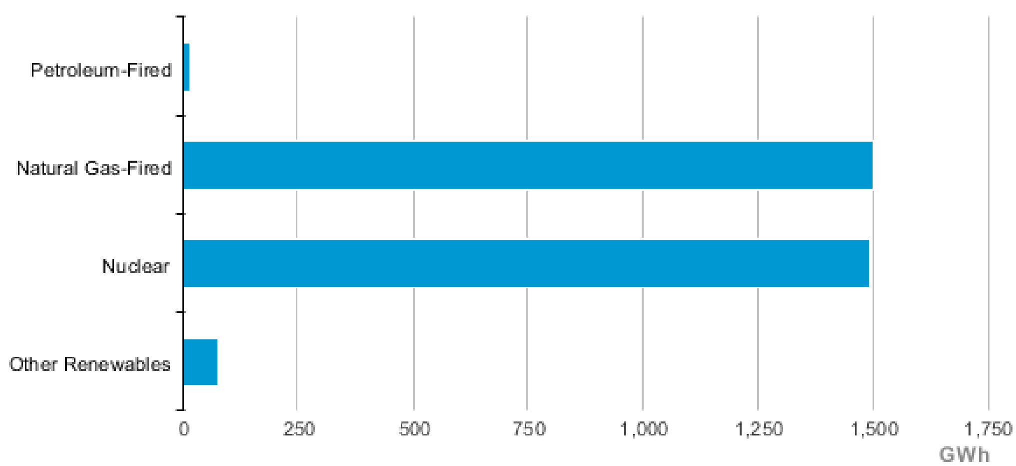
Massachusetts Net Electricity Generation by Source, Sep. 2015



*EIA data and graph

Massachusetts is a mix of both New Hampshire and Maine, using natural gas and nuclear power to as the main sources of electricity production in its generation mix for the month of September.

Connecticut Net Electricity Generation by Source, Sep. 2015



*EIA data and graph

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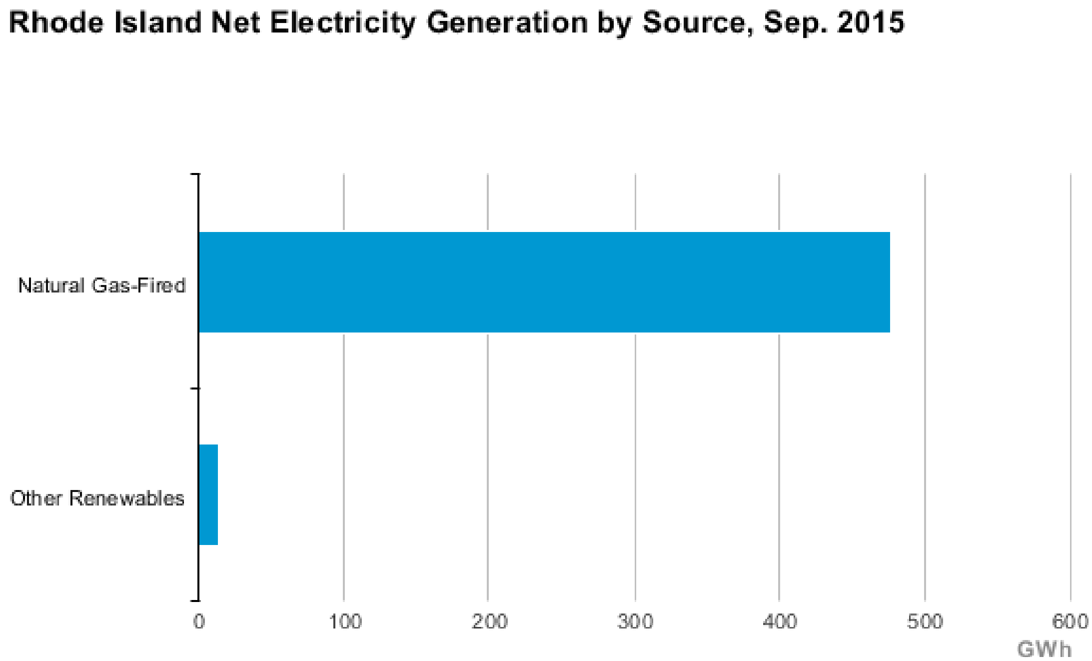
The last two graphs again show that natural gas is the dominating electricity production type in September 2015 for the generation mix of these New England states.



*EIA data and graph

All New England states besides Vermont are very similar to Maine with natural gas being a the major contributor to electricity production. New Hampshire produces the majority of its electricity from nuclear power, which is beneficial to the environment because nuclear power production emits far fewer CO2 emissions than petroleum or natural gas.[13] Referencing the final graph one can see that it is more environmentally friendly then natural gas and very similar to the level of CO2 emissions hydropower produces.

The hypothesis that C02 emissions from the transportation sector will be lower if we use electric vehicles instead of conventional vehicles, but not as low as if only using the type of electricity that is least C02 emitting to power electric vehicles, is consistent with the estimated calculations and values of emissions being produced by electric vehicles based on the type of electricity used to power the transportation sector in each state**.** Many assumptions were made in these calculations. To calculate the percent of vehicles that are electric the data was from

[13] New Hampshire." *US Energy Information Administration*. US Department of Energy, 2015. Web. <http://www.eia.gov/state/?sid=NH#tabs-4>.

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two separate years, and thus is clearly an estimated percentage. The kWh to drive 100 miles for conventional and electric cars was a general estimate because all cars have different gas mileage and some electric cars are more efficient than others, but for the sake of the calculations picking one number to represent the type of vehicle was most rational. Overall the data showed significance and if calculating the difference between all of the New England states, one could most likely see how changing the generation mix can really have a dramatic impact on CO2 emissions for this currently small percentage of vehicles. However, if it grows to take up a much larger percentage of private motor vehicles the impact will even greater.

People underestimate the impact types of electricity used to power electric cars has on emissions for two reasons. First, they do not see the emissions associated with electricity production, which occurs at another location and is not visible to the public. Second, the number of electric vehicles is still small, so we do not notice the impact on overall electricity consumption. One can assume the percentage of electric vehicles in the entire United States is most likely even smaller that what is represented in these states. Research conducted by Lingzhi Jin and Stephanie Searle reveals that the coastal states have a higher percentage of electric vehicles than the rest of the US, with California leading the charge, and Vermont, Massachusetts, and Connecticut all close behind when taking into account population size.[14]

The United States cannot compare itself with other countries when examining the prospects for reducing emissions through the use of electric cars, because the electricity is not produced the same way. Norway is a perfect example of a country we look at to help convince consumers that electric vehicles have a huge impact helping the environment and emissions levels, however in 2012 Norway had almost 97% of its electricity produced by hydropower, which emits a very low amount of CO2. Overall we can see that if the electric vehicle industry does grow as rapidly as predicted, it will have an effect on the electricity sector and emissions will rise from this sector if we do not shift production to the more environmentally-friendly systems that other countries have been using.

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[14] Jin, Lingzhi, and Stephanie Searle. "Evaluation Of State-Level U.S. Electric Vehicle Incentives." (n.d.): n. pag. *The International Council On Clean Transportation*. ClimateWorks Foundation, Oct. 2014. Web. 21 Nov. 2015.
<http://www.theicct.org/sites/default/files/publications/ICCT_state-EV-incentives_20141030.pdf>.

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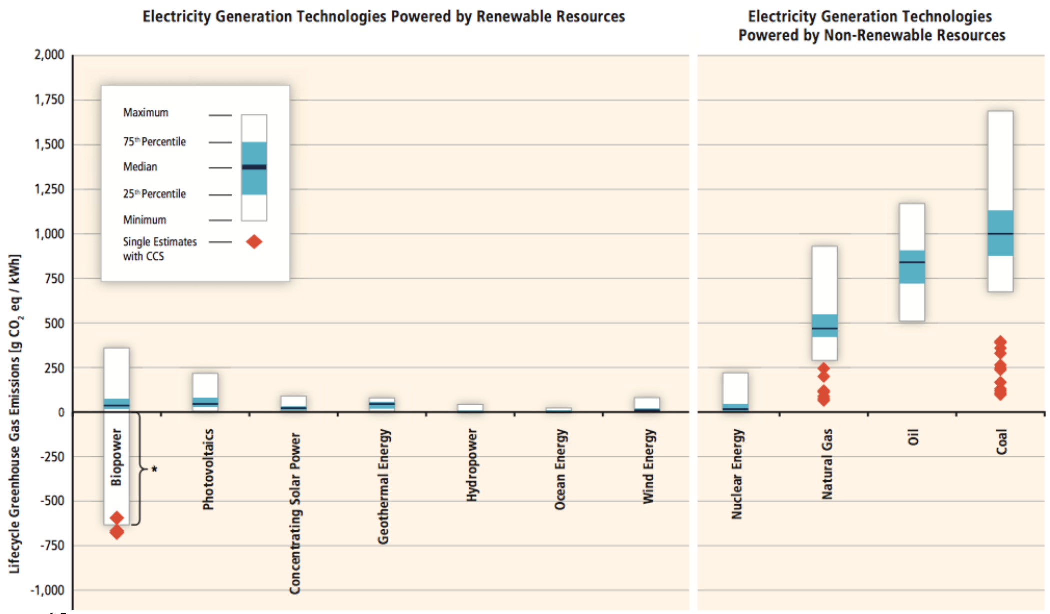

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[15] Sathaye, Jayant. "Renewable Energy Sources and Climate Change Mitigation." *IPCC SRREN: Full Report*. Intergovernmental Panel on Climate Change, 2015. Web. 29 Nov. 2015. <http://srren.ipcc-wg3.de/report/>.

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